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# Solid Desiccant Dehumidification and Regeneration Techniques

***Abstract* - This paper presents various aspects of solid desiccant dehumidification with the focus on regeneration of desiccant with solar collector. This technology can be used to reduce the energy consumption and environmental impact of mechanical dehumidification system. In this paper, the principles underlying the operation of desiccant dehumidification systems are recalled and their actual technological applications are discussed. Some commented examples are presented to illustrate how the desiccant dehumidification can be a perfective supplement to other dehumidification systems such as traditional vapor compression air conditioning system.**

***Index terms-*** Dehumidifier, regeneration, solar collector, solid desiccant, Silica gel

## I. INTRODUCTION

Dry air plays a vital role for improving the process, product or conditions in many industries such as food production, pharmaceutical production, industrial chemicals production etc. It is also required in warehouse storage, packaging equipment rooms, hygroscopic raw materials storage, organic plant dehydration and inorganic products [1].

Some examples of industrial processes/manufacturing units along with their effects of humidity controls are:

- To prevent corrosion and improve production of lithium batteries.
- To prevent condensation and corrosion on metal surface in computer and electronic equipments.
- To prevent deterioration of products in confectionary and pharmaceutical packing.
- To optimize seed moisture level and minimize microbial deterioration in seed and grain storage houses.
- To improve the product finish by preventing condensation on the mould surfaces in plastic molding.

Humidity control is also related with the growth of fungi and bacteria which causes spoilage of products and affects the health of living beings. The range of the growth of fungi and bacteria with respect to relative humidity is shown in Figure 1. The most common methods for producing dry air are cooling based dehumidification; Compression based dehumidification and chemical dehumidification.

In the past, methods of cooling based dehumidification and compression based dehumidification have been used. In the cooling based dehumidification method (vapour compression system), the dry air is produced by cooling the atmospheric air below the dew point temperature. In other words below the dew point temperature, water vapour gets condensed and separated from the air.

This method has the following advantages:

- Light weight and compact size.
- Independent of weather conditions.
- Suitable for low quantity of dry air.
- Easy handling of operations and installation.

Figure 1 shows increase in microbial growth in stored grain as a function of relative humidity [2]. But a drawback of above method is that it cools the air below the dew point temperature so it consumes more electricity which is high grade energy. Now a day air conditioner is becoming the basic need in human life and in future, it is expected to play a vital role in our lives. Conventional air conditioner based on vapour compression system utilizes chloro fluoro carbon (CFC) and hydro chloro fluoro carbon (HCFC) which are harmful to the environment. Other common method of producing dry air is compression based dehumidification. When air is compressed, the dew point temperature of moist air is raised to a point where moisture can be condensed from the air at a higher temperature.

Advantages of above method are

- Compact size and light weight.
- Independent of weather conditions.
- It is very beneficial where small amount of dry air is needed for humidity control.
- It is suitable for using in space because of the availability of compressed air.

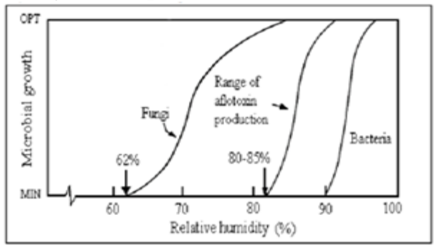



Figure 1. Range of growth of fungi and bacteria with respect to relative humidity [2].

Some drawbacks are initial cost and running cost are very high. The amount of cooling water required for after cooling makes it very impractical for large volume of air and it is very difficult to handle the high range of pressure required with proper safety. The simple and effective way of producing the dry air is by using chemical dehumidification i.e. solid desiccant. Solid desiccant attracts moisture due to vapour pressure difference without any change in their physical and chemical composition. The amount of vapour adsorbed is proportional to the surface area of desiccant due to its enormous affinity to

adsorb moisture and considerable ability to hold water. The saturated desiccant is regenerated by passing hot air through it so that desiccant can be used again. Various solid desiccants like silica gel, activated charcoal, activated alumina and zeolite can be used [3].

## II. DESICCANT DEHUMIDIFICATION

Air dehumidification can be achieved by two methods:
(1) Cooling the air below its dew point and removing moisture by condensation, (2) Sorption by a desiccant material. Desiccants in either solid or liquid forms have a natural affinity for removing moisture. As the desiccant removes the moisture from the air, desiccant releases heat and warms the air, i.e., latent heat becomes sensible heat. The dried warm air can then be cooled to desired comfort conditions by sensible coolers (e.g. evaporator coils, heat exchangers, or evaporative coolers). To reuse the desiccant, it must be regenerated or reactivated through a process in which moisture is driven off by heat from an energy source such as electricity, waste heat, natural gas, or solar energy.

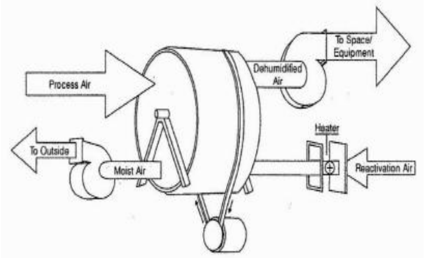



Figure 2. Solid desiccant wheel dehumidifier [4]

For industrial applications, solid desiccant cycles use dual-column packed-bed dehumidifiers; however, the most appropriate dehumidifier configuration for air-conditioning applications is the rotary wheel (Figure 2). The air to be dehumidified enters the system, comes into contact with the desiccant wheel, and exits the dehumidifier hot and dry. The wheel is then rotated so that the desiccant portion that has picked up moisture is exposed to hot reactivation air and its moisture removed.

Since the air leaving the desiccant is heated because of the release of heat adsorption, there is a need for cooling the dried air in cooling applications. This can be accomplished with a sensible heat exchanger such as a heat pipe or with a standard vapor-compression cooling coil. Figure 3 shows schematics of a desiccant air conditioner incorporating direct-evaporative coolers and a rotary solid-desiccant wheel. Figure 4 is a schematic of a liquid-desiccant dehumidification system. In a liquid system, there are two separate chambers, one to perform the dehumidification (or conditioning) and the other to reactivate (or regenerate) the desiccant. The processed air from the dehumidification chamber enters into the conditioned space. The desiccant, leaving the dehumidification chamber containing absorbed moisture, goes through a heat exchanger and down to the regenerator, where heat is added to remove the moisture. The liquid desiccant is pumped continually between the two chambers when dehumidification is needed.

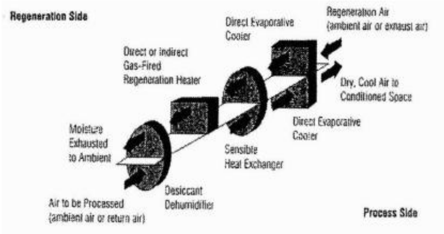



Figure 3. Schematic of a solid desiccant air conditioner [4]

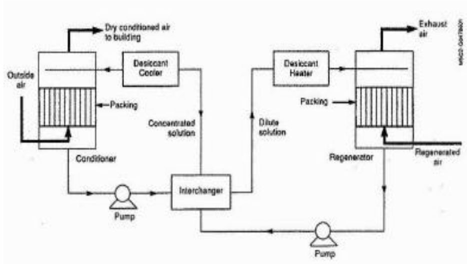



Figure 4. Schematic of a liquid desiccant dehumidification system [4]

Pesaran et al. [4] provide a complete report with approximately 900 citations on various desiccant cooling cycles and past research and development. An excellent tutorial on psychometrics, methods of dehumidification and many applications are presented in a dehumidification handbook by Harriman in 1990[5]. A special ASHRAE publication (ASHRAE, 1992) contains a collection of papers on desiccant system applications, low-level humidity control, and moisture load calculations.

## III. SOLID DESICCANT DEHUMIDIFICATION

### *A. Radial Flow Rotary Desiccant Dehumidifiers*

M. M. Elsayed et al.[6] developed a model to predict the steady periodic performance of a radial flow desiccant wheel (Figure 5). The model is expressed in terms of the same dimensionless parameters that are commonly used in modeling of the conventional axial flow desiccant wheel. In addition a dimensionless geometrical ratio of the volume of the matrix to the volume of the wheel core is found to affect the performance of the wheel. A finite difference technique on staggered grid is used to discretize the governing dimensionless equations. The discretized equations are solved to predict the performance of the desiccant wheel at given values of operation parameters. A sensitivity study is carried out to investigate the effect of changing any of these parameters on the performance of the wheel. The performance of the radial flow desiccant wheel is compared with that of the conventional axial flow desiccant wheel having the same values of the operation parameters.

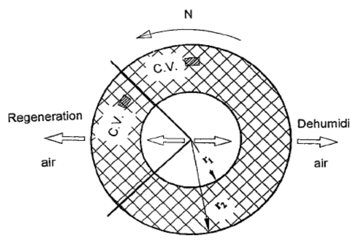



Figure 5. Radial flow desiccant wheel [6]

*B. Desiccant Dehumidification with Hydronic Radiant Cooling System for Air-Conditioning Applications*

Ahmaduf Ameen et al.[7] discusses the feasibility of hybrid desiccant dehumidification system combined with chilled ceiling for air-conditioning applications in humid tropical climates. The study presents a design/operation guide of the hybrid system. The study also indicates definite merit of the hybrid system when the ventilation air requirement for the conventional system is above a certain threshold. This is particularly so in many practical applications, where a high ventilation air requirement is desirable or mandated, such as operating theaters and certain hospital wards. A trial run on the facility indicates the viability of the scheme particularly the absence of condensation/sweating of chilled panels. In the same context the facility developed to conduct experiments is described. For a space loading of 0.1 KW/m$^2$, any ventilation rate above 2% for a conventional system offers opportunity downsizing chiller capacity of the hybrid system. Based on an indicative energy analysis, the proposed hybrid system become more energy efficient than a conventional system when the required ventilation rate is 30% and above.

*C. Rotary desiccant dehumidification and air conditioning*

D. La, et al. [8] developed Rotary desiccant air conditioning system, which combines the technologies of desiccant dehumidification and evaporative cooling, is advantageous in being free from CFCs, using low grade thermal energy and controlling humidity and temperature separately. Compared with conventional vapor compression air conditioning system, it preserves the merits of environment friendly, energy saving, healthy, comfortable, etc. ongoing research and development works suggest that new desiccant materials and novel system configurations have significant potential for improving the performance and reliability and reducing the cost and size of rotary desiccant dehumidification and air conditioning system, thereby increasing its market competitiveness and breaking out the current fairly small niche market. For the purpose of providing an overview of recent efforts on these issues and showing how rotary desiccant air conditioning systems can be designed and coupled to available thermal energy, this study presents and analyzes the status of rotary desiccant dehumidification and air conditioning in the following three aspects: The development of advanced desiccant materials, the optimization of system configurations and the utilization of solar energy and other low grade heat sources, such as solar energy, district heating, waste heat and bio energy. Some key problems to further push forward the research and development of this technology are also summarized.

*D. Isothermal Desiccant Operated Humidity Pump (DOHP)*

Hamed A. M. [9], Compared desiccant dehumidification system with the vapor compression heat pump, in general, functions as humidity pump. The function of the humidity pump is to transfer the humidity of room air (indoor condition) to the outside air (outdoor conditions). In most cases, the indoor humidity is objected to be lower that of the outdoor air. The energy required to power such systems is mainly the regeneration heat required to heat the desiccant regenerator. The basic concept of humidity pump is demonstrated in Figure 6. In this, air at the indoor conditions is dehumidified isothermally through the dehumidification process R-O, where the conditions R and O represent the room and outside conditions, respectively. The system which carries out this process is called a humidity pump (HP). However, isothermal absorption of water vapor from air can be carried out with continuous cooling of the desiccant during the process. At the end of absorption the desiccant must be regenerated to remove the absorbed water and re-concentrate the solution.

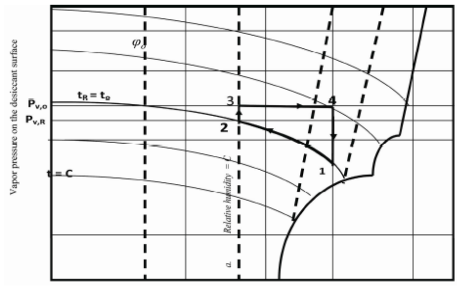



Figure 6. Vapor pressure on the desiccant surface vs desiccant concentration of the absorption-regeneration cycle [9]

The absorption-regeneration cycle, which can be applied, for operation as a humidity pump, is shown in Figure 6. The theoretical cycle is plotted on the vapor pressure-concentration diagram for the operating absorbent and consists of four thermal processes which are:

- Process 1-2: isothermal absorption of water vapor from room air;
- Process 3-4: constant vapor pressure regeneration of absorbent and
- Process 4-1: constant concentration cooling of absorbent.
- Process 2-3: constant concentration heating of the absorbent;

The thermal processes of this cycle are carried out between two concentration limits; $x_1$ and $x_2$ and the cycle has another operation limits which are its maximum regeneration temperature, $t_4$; condensation vapor pressure, $P_{vo}$ and maximum absorption vapor pressure, $p_{vR}$. Evaluation of these operation limits is important from the point of view of system design and construction. Therefore, description of the effect of weather conditions on the cycle operation is presented as follows: if the room temperature is equal to $t_1$, and strong solution concentration is $x_1$, absorption process starts only when the vapor pressure on the absorbent surface is lower than the vapor pressure in the room air $P_{vR}$. Theoretically, absorption continues from 1 to 2, i.e. ends at equilibrium condition when the pressure of vapor on the absorbent surface is the same as that in room air. When the absorption process ends, absorbent is pumped to the regenerator and heated from an external source. Regeneration of weak absorbent can be carried out at constant pressure. The vapor pressure on the absorbent

surface at point 2 is equal to $P_{vR}$, which is determined in terms of room relative humidity and temperature. Constant pressure condensation at this pressure requires that the condensation temperature is the saturation temperature of water vapor corresponding to the vapor pressure of the outdoor air $P_{VO}$. When condensation is assumed to be at ambient temperature, weak solution must be heated from $t_2$ to $t_3$ where as concentration is constant and vapor pressure increases from $P_{VR}$ to Pvo, which is the saturation pressure of vapor corresponding to ambient (outdoor) conditions. The increase in temperature from $t_2$ to $t_3$ depends on the relative humidity of air or the weak solution concentration, $x_2$, which depends also on the relative humidity at the given ambient temperature. During the constant pressure condensation, solution concentration increases from $x_2$ to $x_4$. The maximum regeneration temperature depends on the available heat source and the limits required of desiccant concentration. Strong (regenerated) solution at point 4 is not able to absorb vapor from room air due to its higher vapor pressure; therefore pressure is reduced again to $p_1$ by cooling from $t_4$ to the room temperature where the cycle ends at point 1.

## III. SOLID DESICCANT REGENERATION

### *A. The regeneration of silica gel desiccant by air from a solar heater with a compound parabolic concentrator.*

Surajitr Pramuang et al. [10] worked on regeneration of silica gel desiccant by a solar air heater for use in an air-conditioning system. The hot air is produced by a compound parabolic concentrator collector (CPC), which has aperture and receiver areas 1.44 and 0.48 $m^2$ respectively. The regeneration temperature can be started at $40^oC$. The regeneration rate and the regeneration efficiency were greatly affected by the solar radiation, but depended only slightly on the different initial moisture contents of silica gel and the number of silica gel beds. The regeneration of silica gel provided by the CPC collector is suitable for a tropical climate where the diffuse solar radiation is high all the year round.

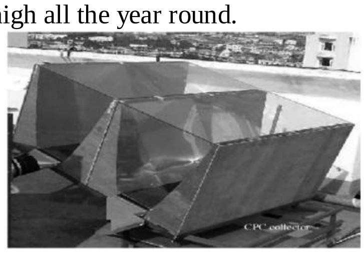



Figure 7. The silica gel container and the compound parabolic collector with the plat plate receiver used for heating air [10]

The hot air is produced by the solar air heater with a compound parabolic concentrator collector. The collector has total aperture area 1.44 $m^2$ and a flat receiver area of 0.48 $m^2$ making a concentration ratio CR=3.0. Each collector has overall dimensions 0.6 m height, 0.6 m width, and 1.2 m length. The receiving surface, which is painted non-selective matt black, forms the upper side of a rectangular air flow duct of depth 0.03 m made of aluminum sheet 0.2 mm thick. The bottom of the duct is insulated with fiber glass 50 mm thick. The optical efficiency and heat loss of the collector are 0.68 and 8.51 $W/m^2K$. As shown in Figure 7, the process air entering the solar air heater is near ambient temperature and has a high relative humidity. After passing through the collector the process air has a higher temperature, and the same humidity ratio but a low relative humidity. The hot air at point 2 passing upwards through the silica gel beds removes the water content of the silica gel grains due to its low relative humidity. At point 3 the outlet air has a higher humidity ratio and a lower temperature than the air at point 2 due to the desorption of water from the silica gel. The silica gel container has horizontal cross section 0.5 m 0.5 m and height 0.6 m. Each silica gel bed has horizontal dimensions 0.5 m 0.5 m and depth 2.5 cm; one or two beds can be placed on the shelves in the container.

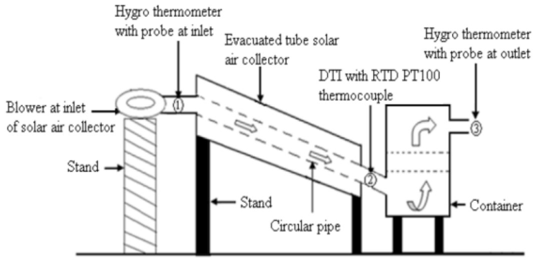
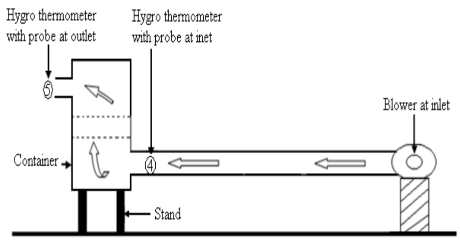



Figure 8. Schematic diagram of experimental setup for regeneration of silica gel, activated alumina or activated charcoal [11]


Figure 9. Experimental setup for regeneration of silica gel, activated alumina or activated charcoal [11]




Figire 10. Schematic diagram of experimental setup for moisture adsorption onto silica gel, activated alumina or activated charcoal [11]

The air speed v is measured by a hot wire anemometer. The air blower is controlled to maintain a constant flow through the system. The air flow rate G is calculated from the equation $G=\rho vA$, where $\rho$ is the air density, A is the cross section area of the air duct.

### *B. Regeneration by Evacuated Tube Solar Air Collector*

Avadhesh Yadav et al.[11] investigated experimentally, the regeneration rates of various solid desiccants like silica gel, activated alumina and activated charcoal. The main

objective in this work is to study the feasibility of regeneration of these desiccants using evacuated tube solar air collector. The performance of evacuated tube solar air collector was investigated, This evacuated tube solar air collector is used to regenerate the various desiccants at different air flow rates and experimental comparison between various types of desiccants and after that its air dehumidification performance are analyzed according to Indian climatic conditions. The results of these experiments are presented. The experiments have been performed to investigate the regeneration rates of silica gel, activated alumina and activated charcoal. To perform various experiments on regeneration, some level of moisture content should be present in the desiccants. For this purpose these desiccants were exposed to humid air over the night. The adsorption process has been carried out immediately after regeneration process in the evening time.


Figure 11. Experimental setup for moisture adsorption onto silica gel, activated alumina or activated charcoal [11]

In this setup, container is integrated with evacuated tube solar air collector. Evacuated tube solar air collector produces hot air for regeneration of various desiccants which are present in the container. In this setup, regeneration of desiccant occurs in day time as shown in figure 8, 9 and adsorption occurs in evening time as shown in figure 10 and 11.

## V. CONCLUSION

Desiccant dehumidification is an established technology that has been used successfully for many years in institutional and industrial applications. Commercial applications are now gaining acceptance. Lowering the cost of desiccant dehumidification systems and improving their performance will clearly provide more opportunities for desiccant dehumidification technology. Desiccant dehumidification systems as add-on modules to electrical refrigeration systems could help to solve the challenges facing the HVAC industry. Increased ventilation rates, need for improved indoor air quality and better humidity controls, phase-out of CFCs, national standards requiring higher efficiency for cooling systems, and desire for lowered peak electric demands.

These factors, and the ability for desiccant systems to solve specific problems, are driving these desiccant technologies to the mainstream of the air-conditioning market.

From the detailed review study the following are emerging research areas in the fields of desiccant dehumidification and cooling system-

1. Numerical analysis and sensitivity analysis of desiccant dehumidification/cooling system.
2. Hybrid desiccant dehumidification/cooling system.
3. Experimental analysis, simulation and mathematical modeling of desiccant dehumidification/cooling dehumidifier.
4. Solar assisted desiccant dehumidification/cooling system.
5. Compounding of desiccant wheel.
6. Application of desiccant cooling dehumidifier for thermal human comfort.

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